

# Nanoenabled Directions for N/MEMS



*MTO Symposium*

**Dennis Polla**  
**DARPA MTO**

**6 March 2007**  
**San Jose, CA**

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>06 MAR 2007</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>Nanoenabled Directions for N/MEMS</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>DARPA</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>DARPA Microsystems Technology Symposium held in San Jose, California on March 5-7, 2007. Presentations, The original document contains color images.</b>					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>UU</b>	18. NUMBER OF PAGES <b>23</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			



# A MTO Nanotechnology Vision

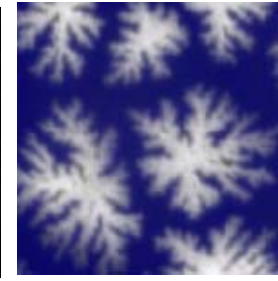
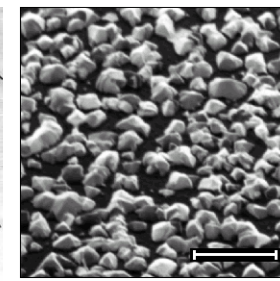
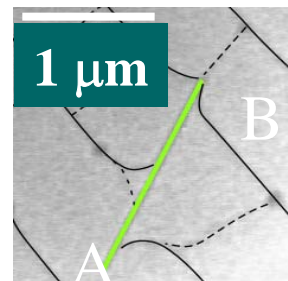
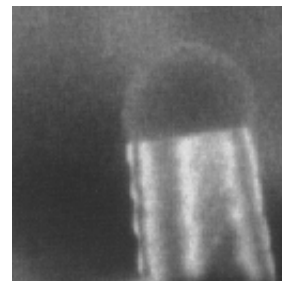
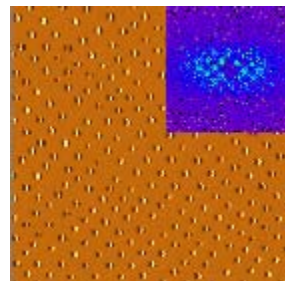
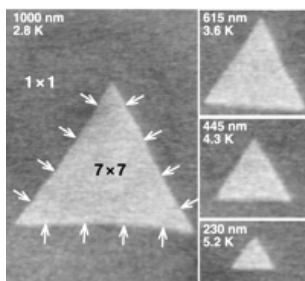
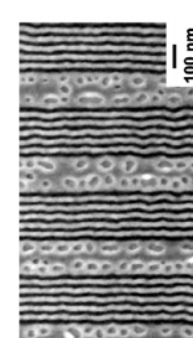
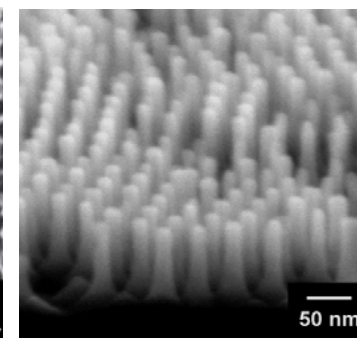
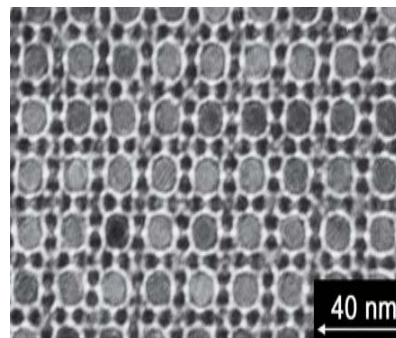
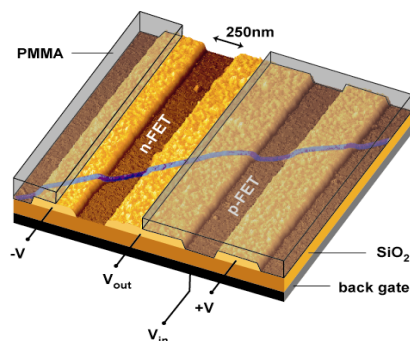
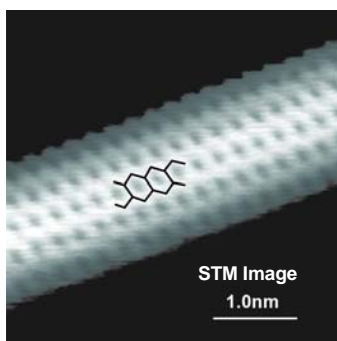
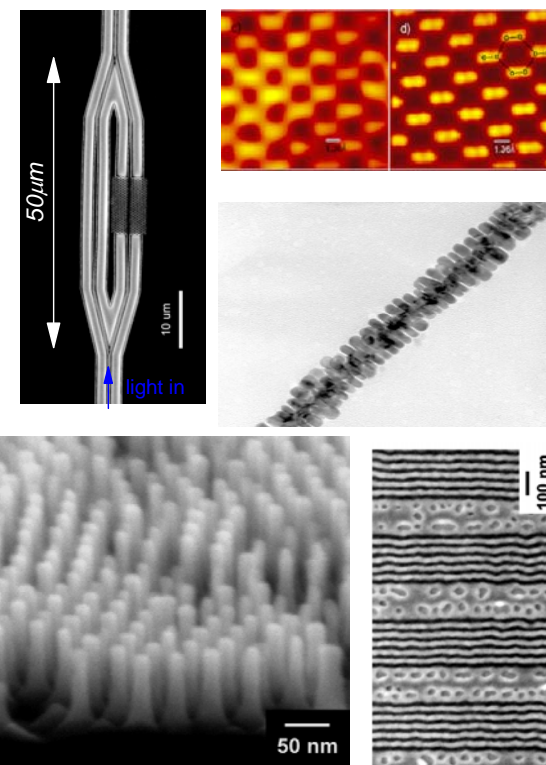


## Nanotechnology Enabled Opportunities

- **Chip-Scale Microfluidic Analyzers**
- **Nanosensors**
- **Nanowires for Sensors and Electronics**

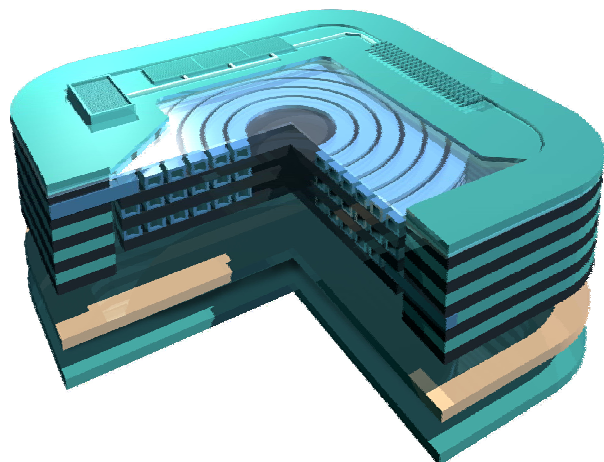
## Two key themes:

- Nanotechnology enables new applications and drives performance
- Nanotechnology is emerging as a key aspect of integrated microsystems



Images courtesy of Philip Wong, Stanford University

Approved for Public Release, Distribution Unlimited



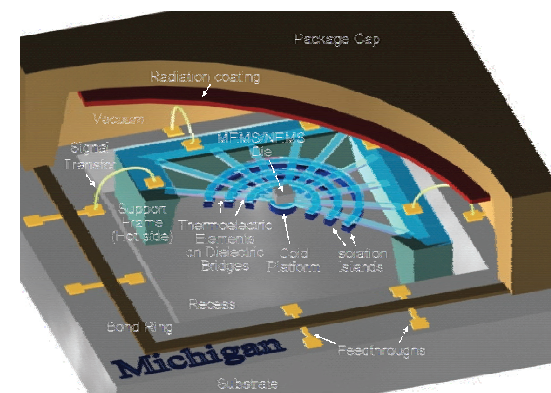
## Micro Gas Analyzers

- CNT Preconcentrators
- Nanomechanical Sensors
- CNT Detectors
- Functionalized Chemiresistors



## N/MEMS S&T Fundamentals

- CNT Sensors
- NEMS Biosensors
- Nanoresonators
- Reconfigurable Nanoelectronics



## Micro Cryogenic Coolers

- Thermal nanostructures
- Nanoenabled cryogenic cooling



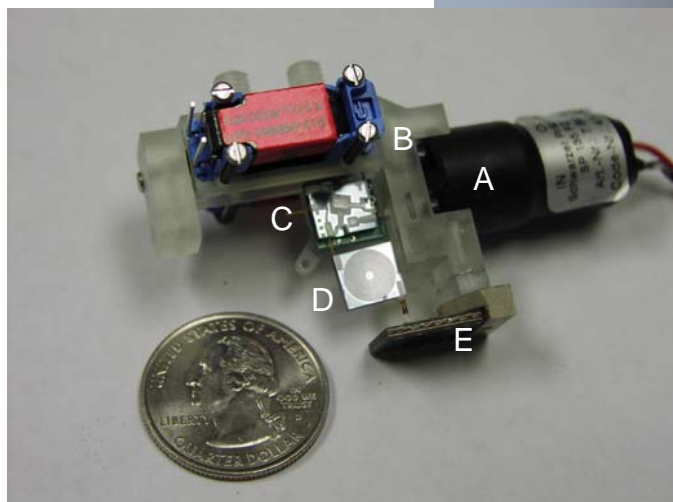
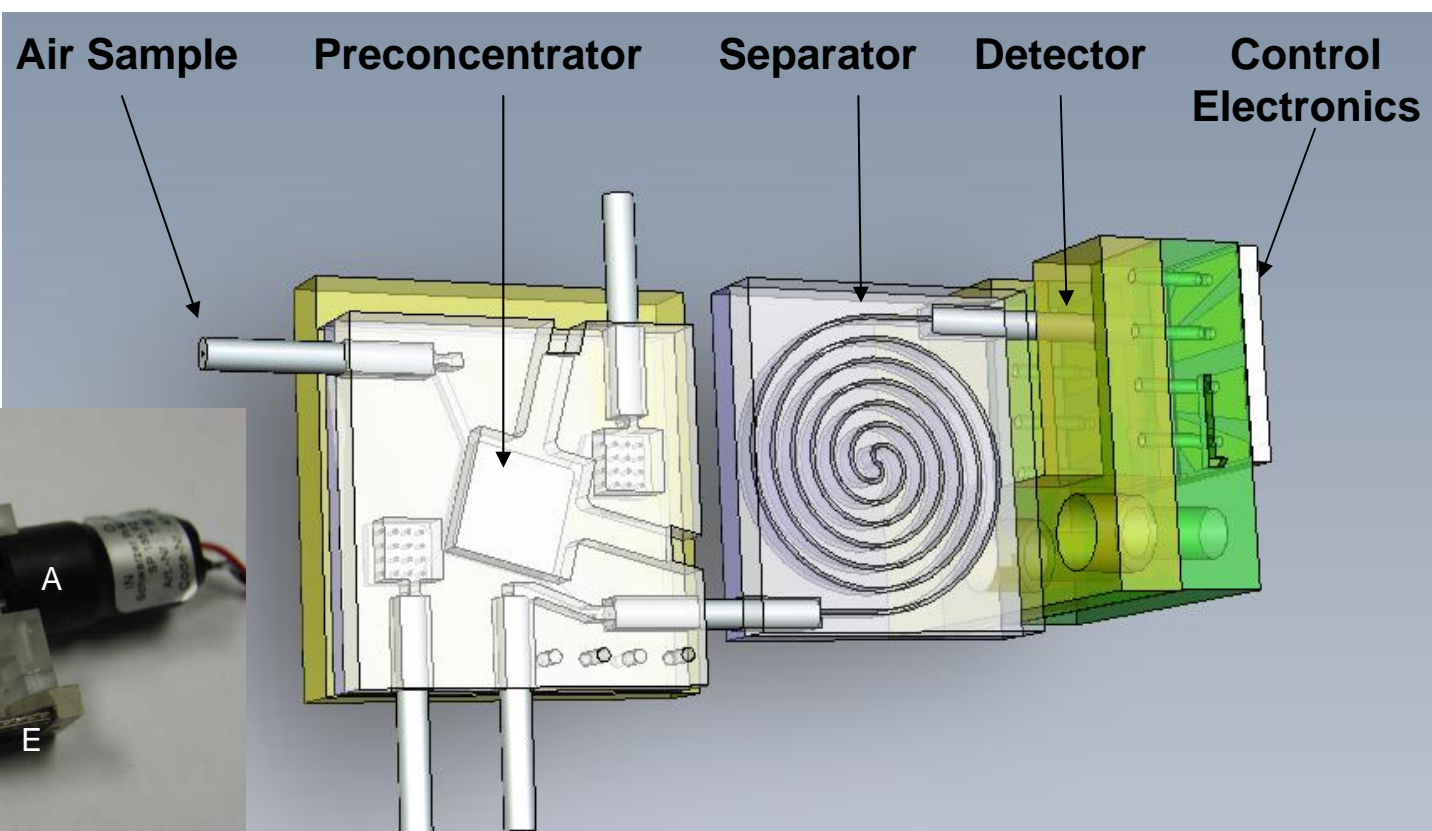
# Chip-Scale Gas Analyzers Program

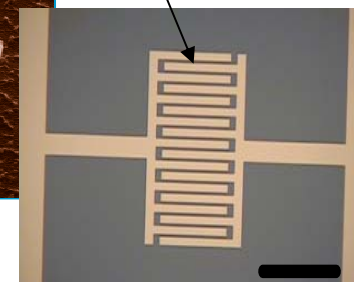
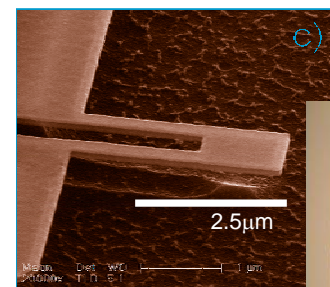
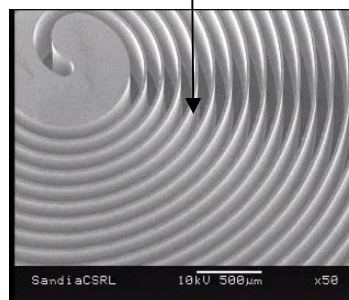
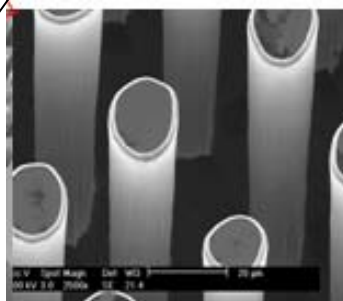
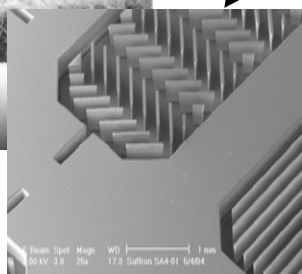
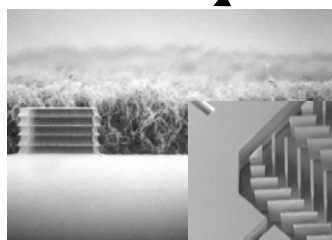
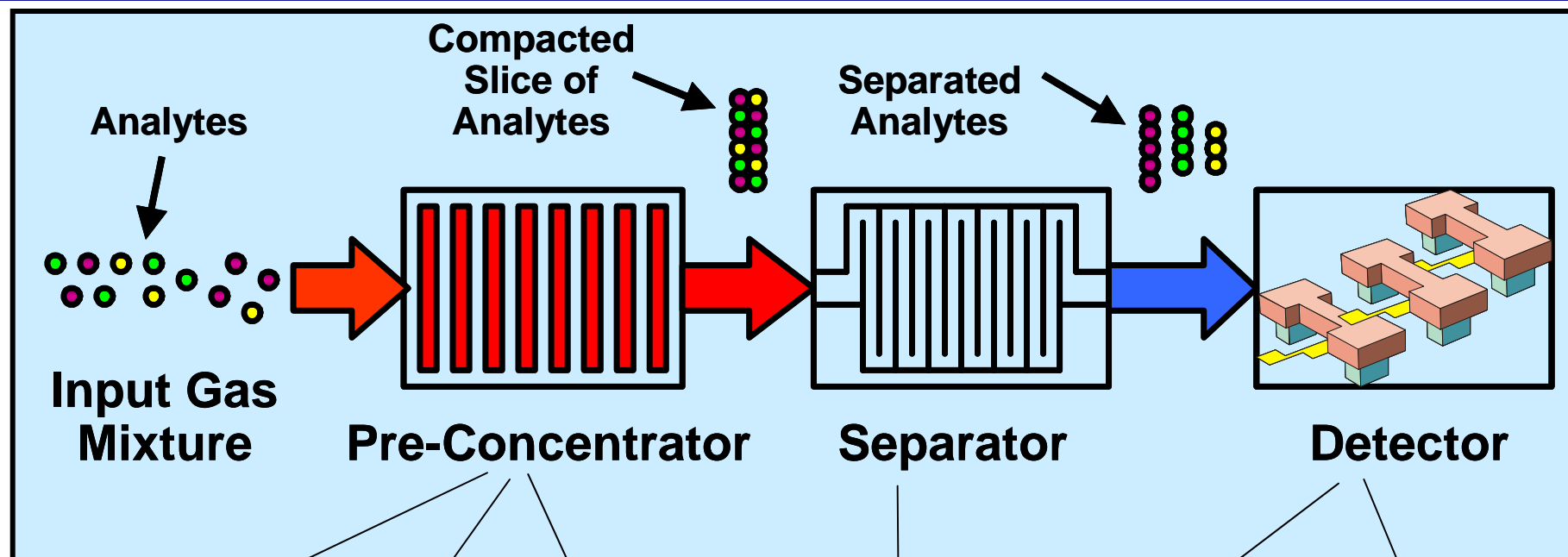
- **Objective:**  
Enable remote detection of chemical agents via tiny, ultra-low power, fast, high sensitivity, chip-scale gas analyzers with low incidence of false positives.



# Sugar Cube – Size Instrument

- **Objective:**  
Enable remote detection of chemical agents via tiny, ultra-low power, fast, high sensitivity, chip-scale gas analyzers with low incidence of false positives.





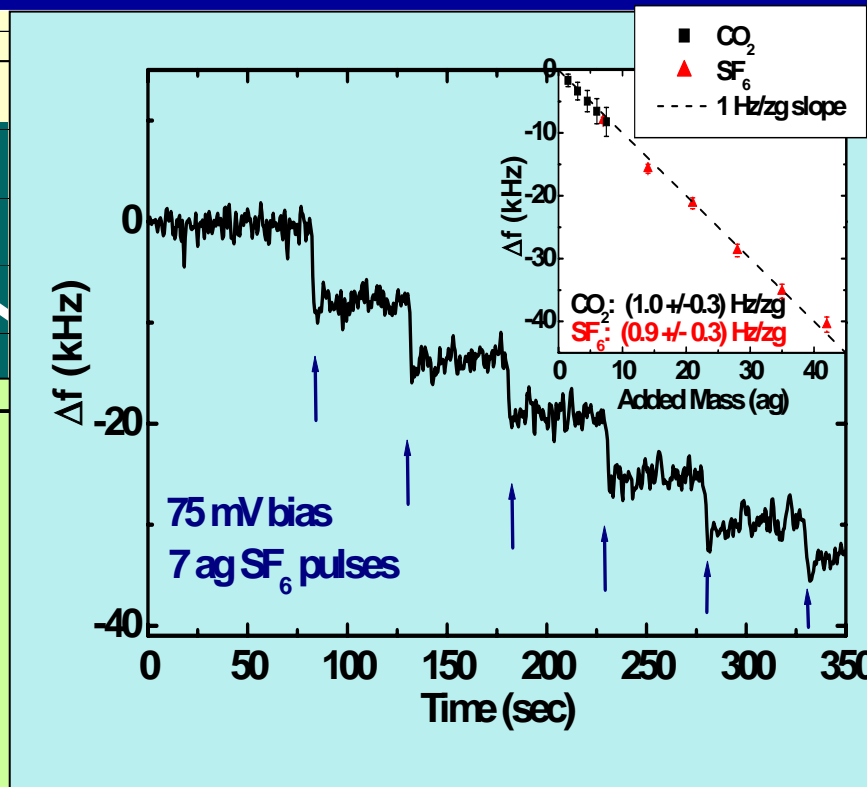
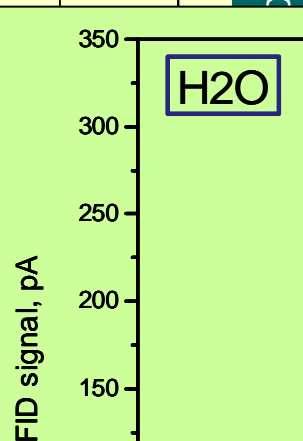
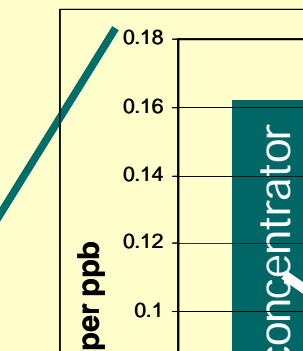
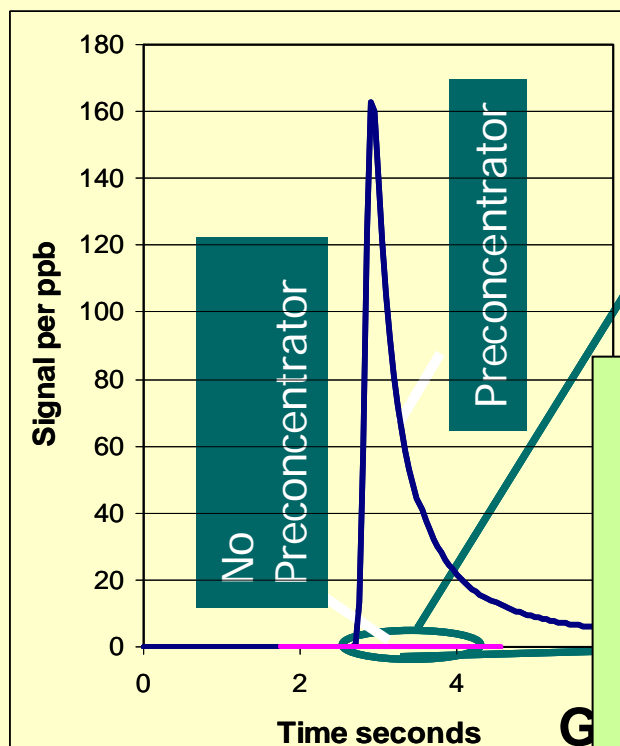
- Very high effective surface area
- Chemical functionalization

- DRIE
- Chemical polishing

- Low proff-mass
- Chemical functionalization



# Enhancement of Performance



## Nanotechnology Lessons Learned:

- Nanotechnology and MEMS (a terrific combination!)

Size: 40,500 cm<sup>3</sup> **20,000X** → 2 cm<sup>3</sup>

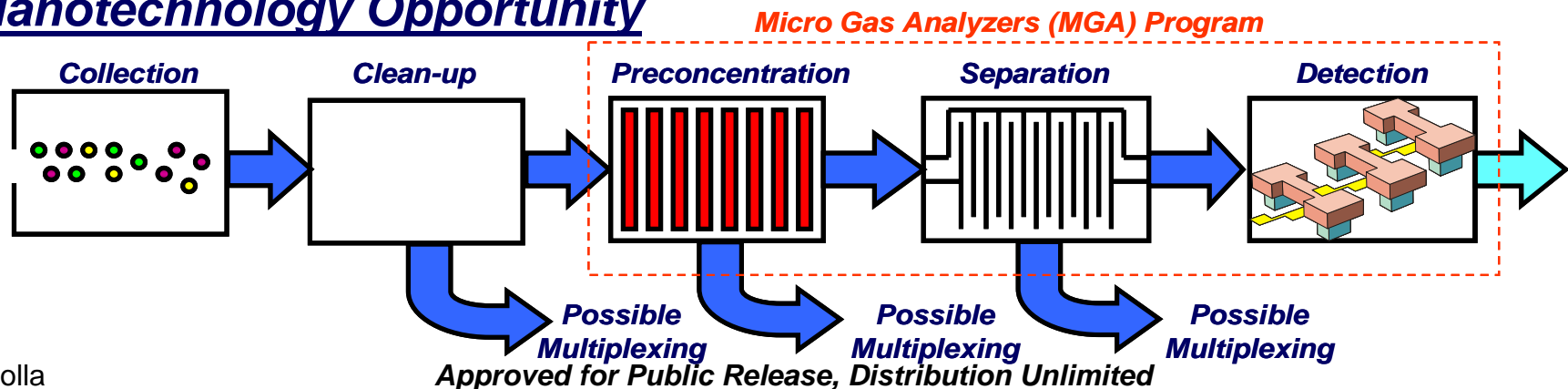
- Nanotechnology enables systems with unprecedented performance:

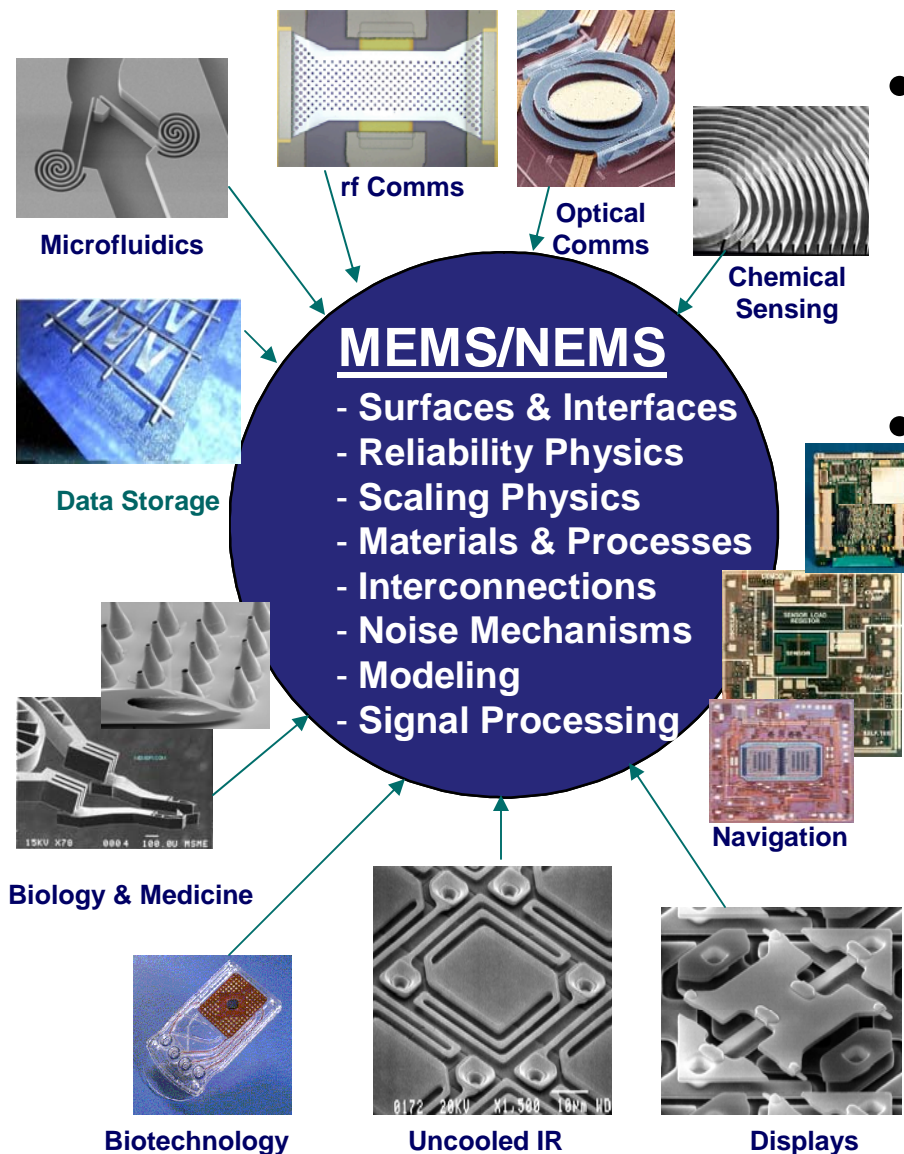
Sensitivity: 1 ppb **1,000X** → < 1 ppt

Analysis time: 15 min **225X** → 4 s

Energy per analysis: 10<sup>4</sup> J **10,000X** → 1 J

## Nanotechnology Opportunity





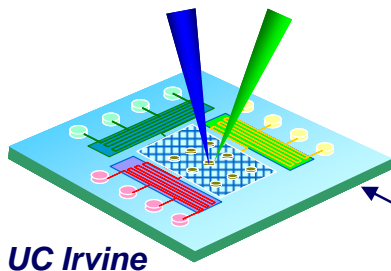
## • Goal:

- Support basic research of importance to DoD in N/MEMS

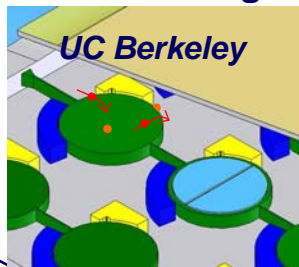
## • Technical Challenges

- Failure Mechanisms and physics
- New materials and processes
- Scaling laws in multiple domains
- Interfaces and interconnects between the macro-micro-nano worlds.

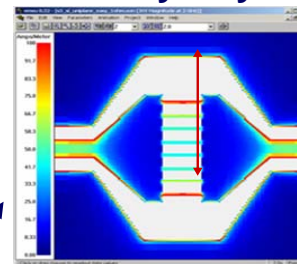
## Microfluidic Processors



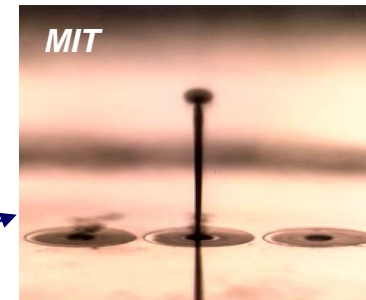
## RF Scaling



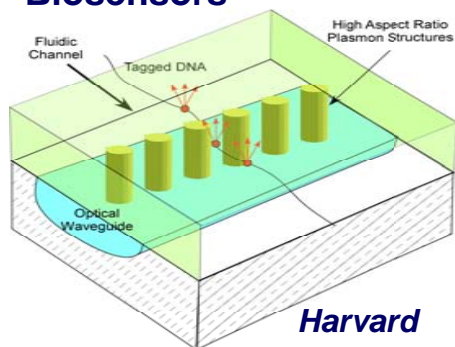
## Reliability Physics



## Non-lithographic Fabrication



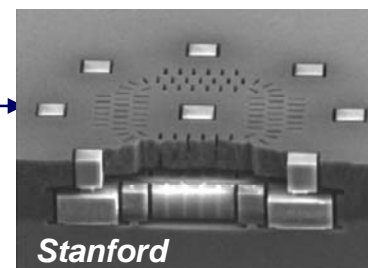
## Biosensors



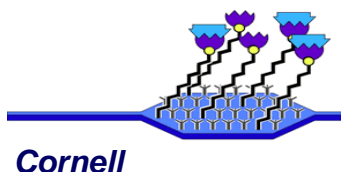
## MEMS/NEMS

- Surfaces
- Interfaces
- Reliability
- Scaling
- Materials
- Fabrication
- Modeling
- Nanostructures

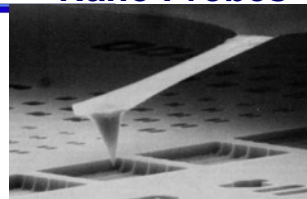
## Materials Interfaces



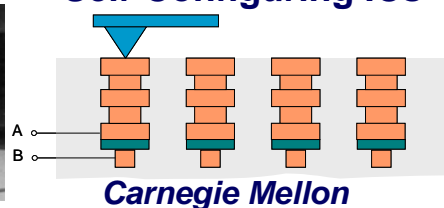
## Functionalized Surfaces



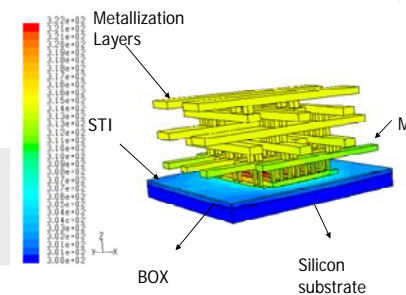
## Nano Probes



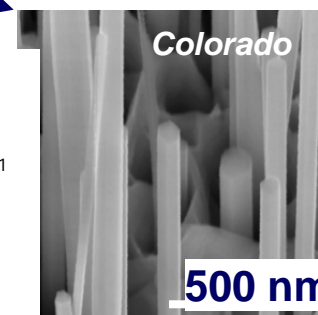
## Self-Configuring ICs



## Multi-Physics Modeling



## Nanowire Sensors







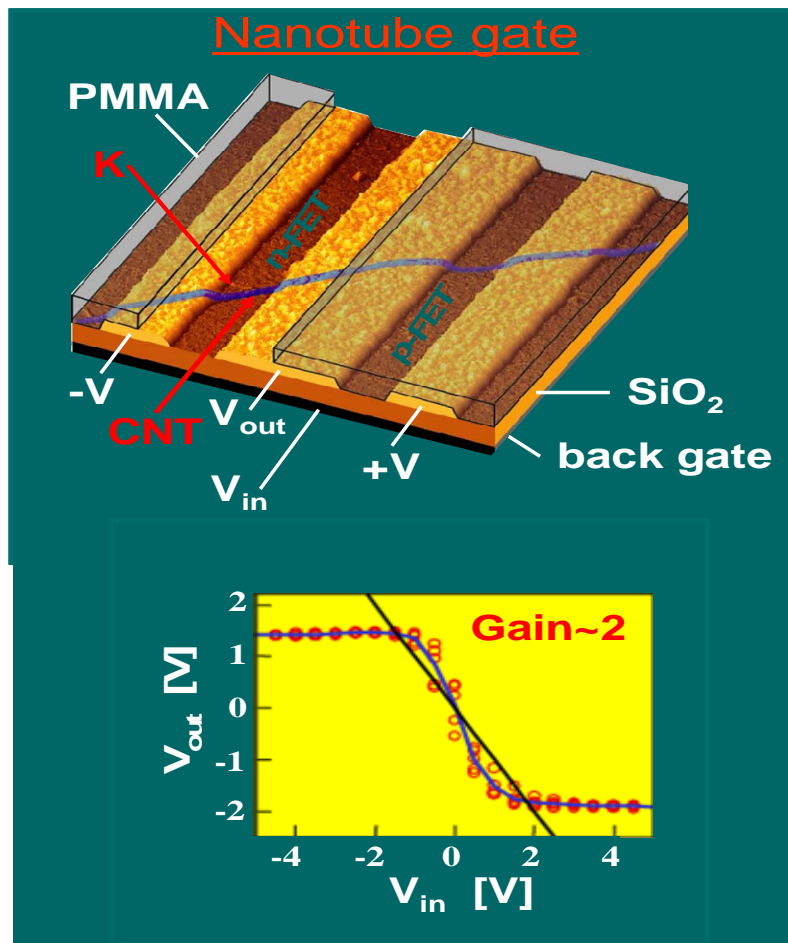
# Nanotechnology Vision



## *Six Nanoenabled Opportunities*

1. **Nanoenabled Electronics**
2. **Nanoenabled Informatics**
3. **Nanoenabled Biotechnology**
4. **Nanoenabled Plasmonics and Photonics**
5. **Nanoenabled Sensors**
6. **Nanoenabled Energy**

## Nanowire Electronics

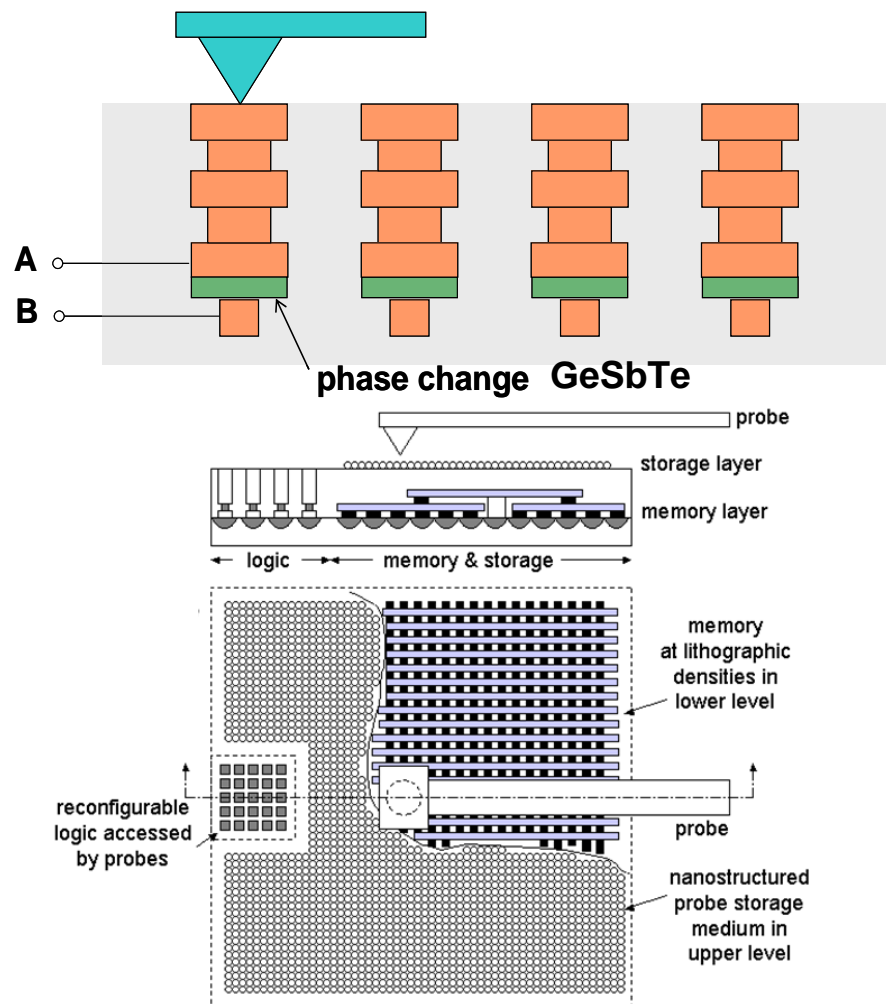


### Key Challenges

- Controlled Growth
- Selective Placement
- Interconnections

D. Polla

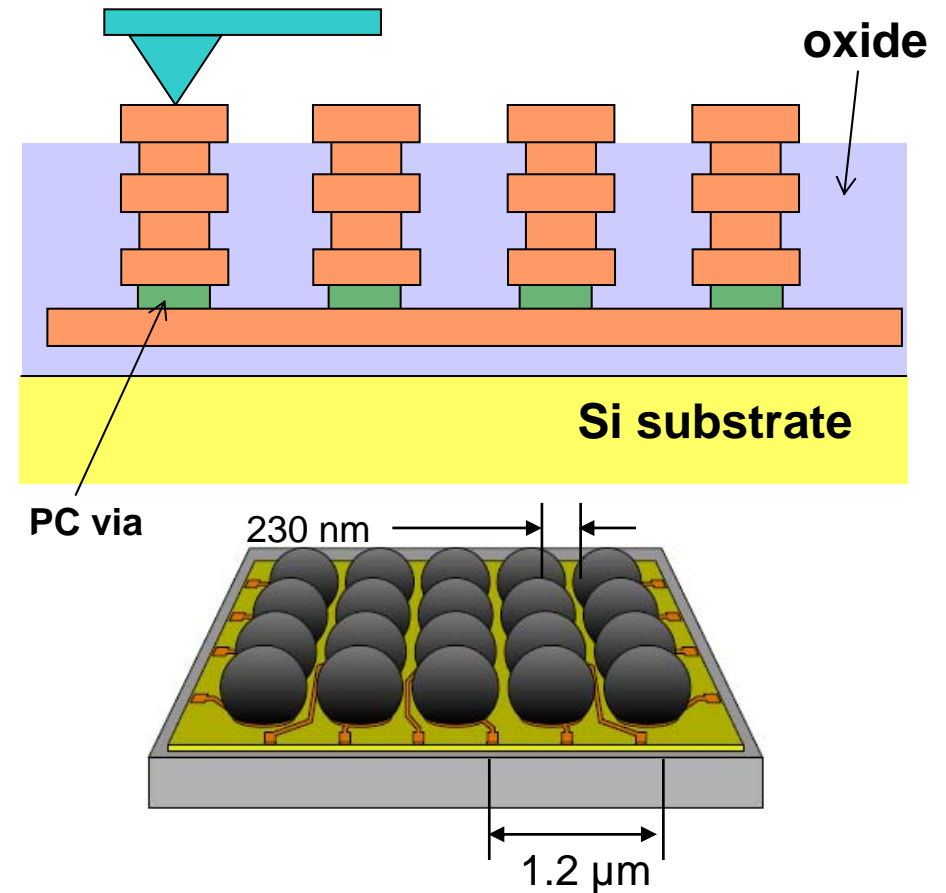
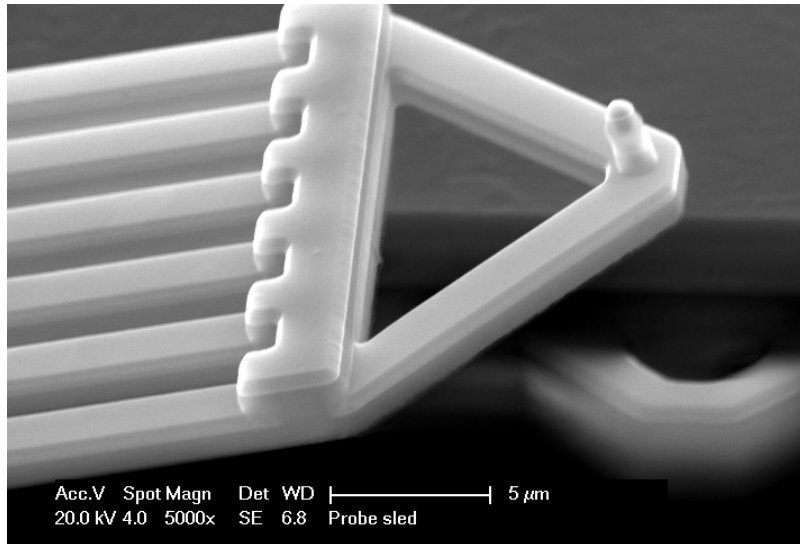
## Self-Configuring Electronics



T. Schlesinger, DARPA  
N/MEMS S&TFundamentals, CMU.

Approved for Public Release, Distribution Unlimited

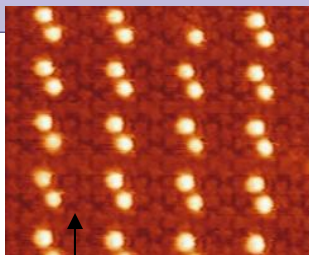
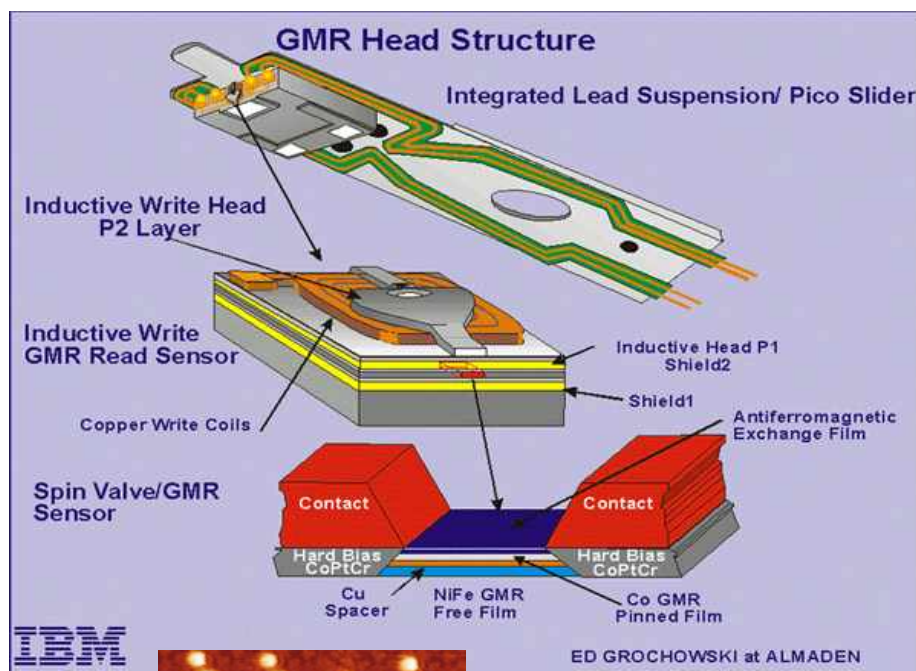
- NEMS Thermal Actuators
- Designed-in stress gradient
- 3  $\mu\text{m}$  post, 230 nm tip area



***Imagine... Dynamically changing the basic function of an electronic chip according to current need.***

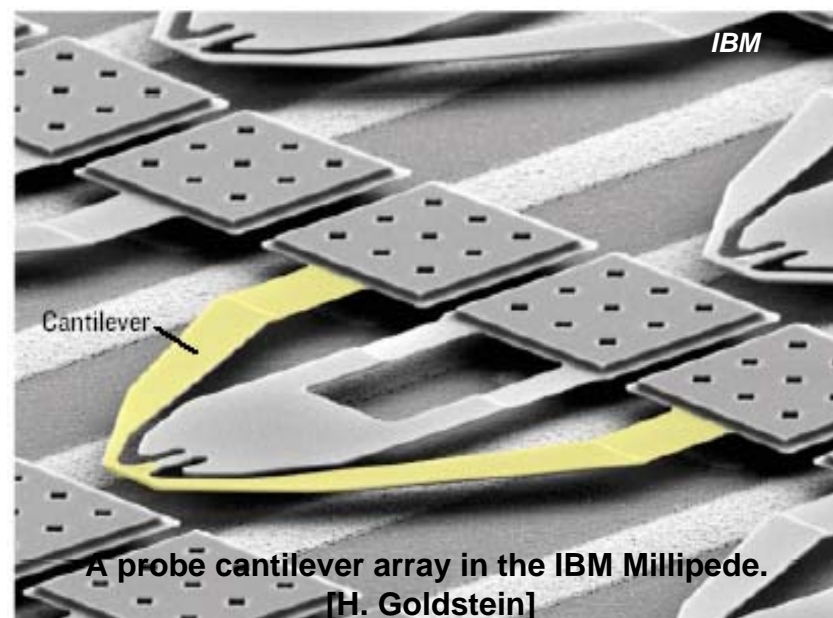
## Storage Media

*Feature size reductions dramatically increase the capacity of storage media. Nanotechnology enables future optical and magnetic storage.*



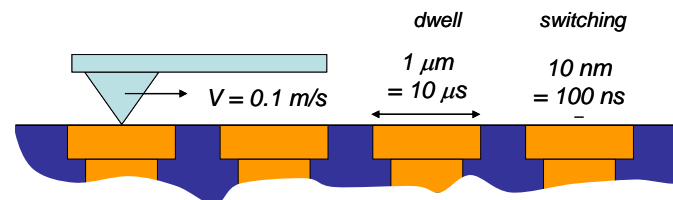
D. Polla [www.nccr-nano.org](http://www.nccr-nano.org)

## Nanomechanical Memory



### Key Aspects

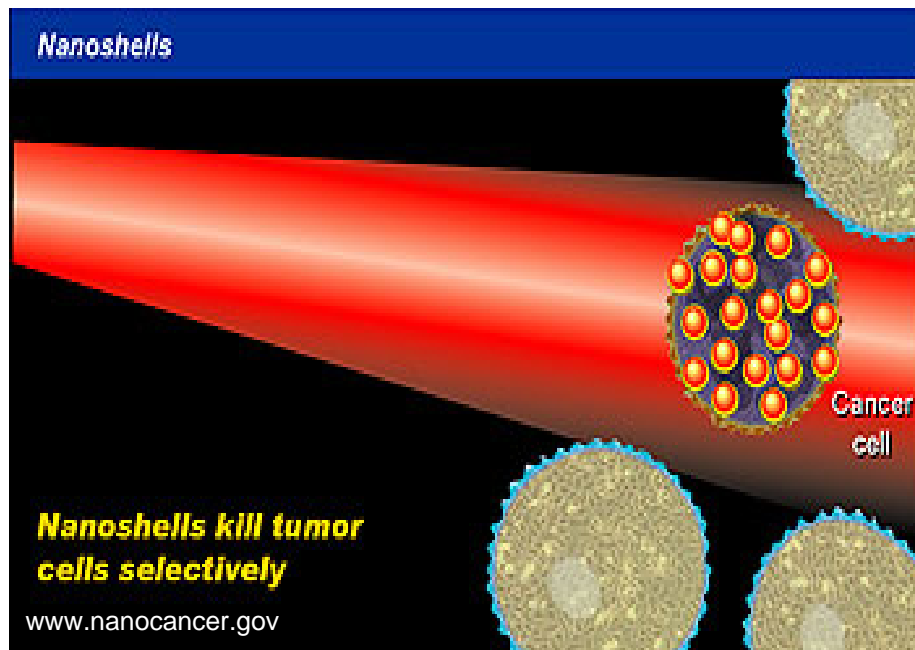
- MEMS probes used for media read/write
- 3 Tbits/inch<sup>2</sup> demonstrated



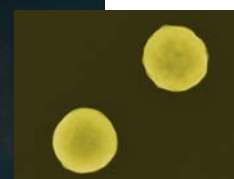
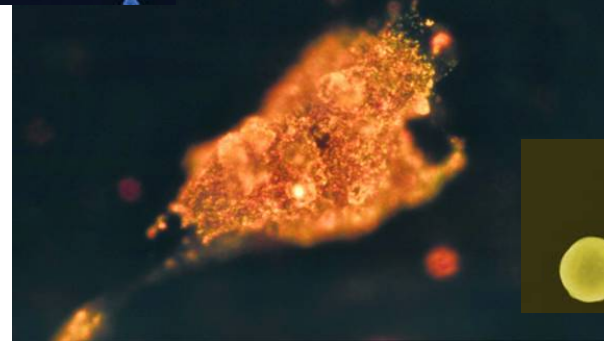
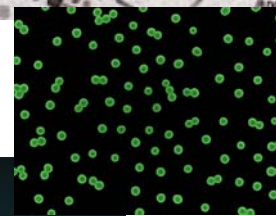
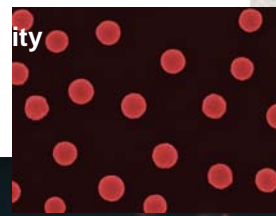
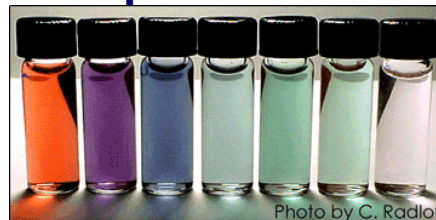


## Medical Therapeutics / Drug Delivery

Therapeutic nanoparticles can be targeted to specific biological sites.

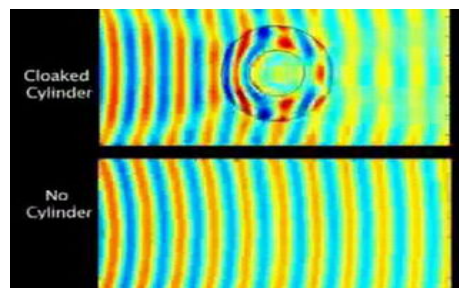
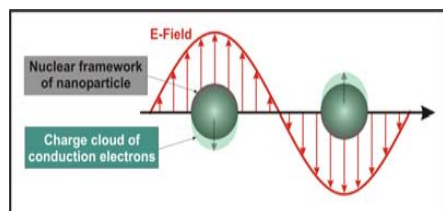
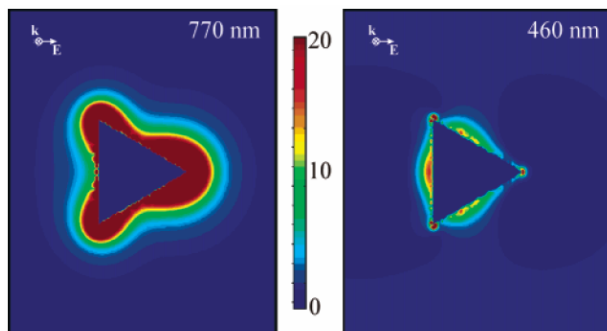


## Nanoparticles



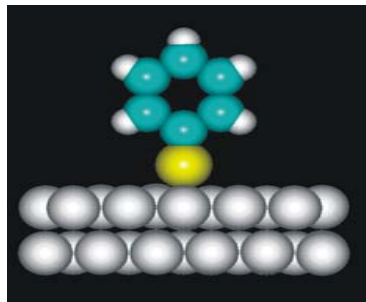
**Imagine...** Site specific targeting of nerves with therapeutic nanoparticles that enhance sensory perception.

## Plasmonics



## Key Challenges

- Control of EM-field Enhancement
- Materials properties

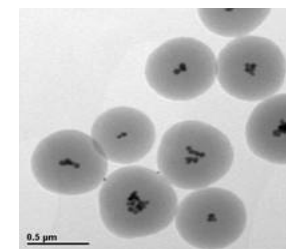
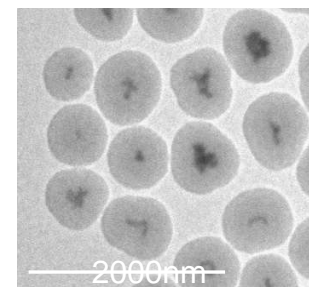
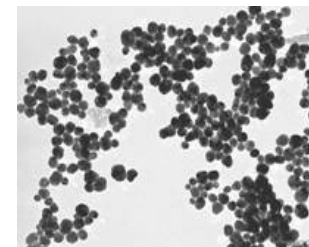
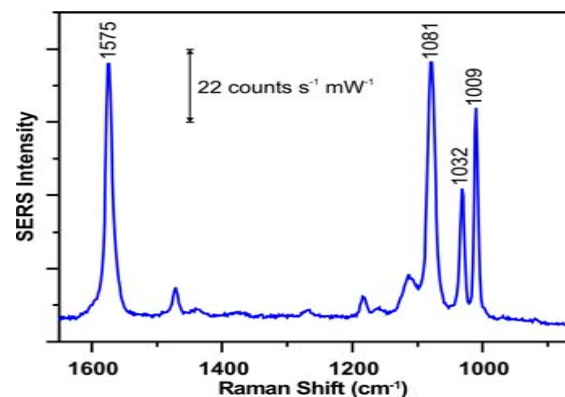


## SERS Nanosensors

Basic physics and materials science associated with SERS nanoparticles as physical, chemical, and biological nanosensors

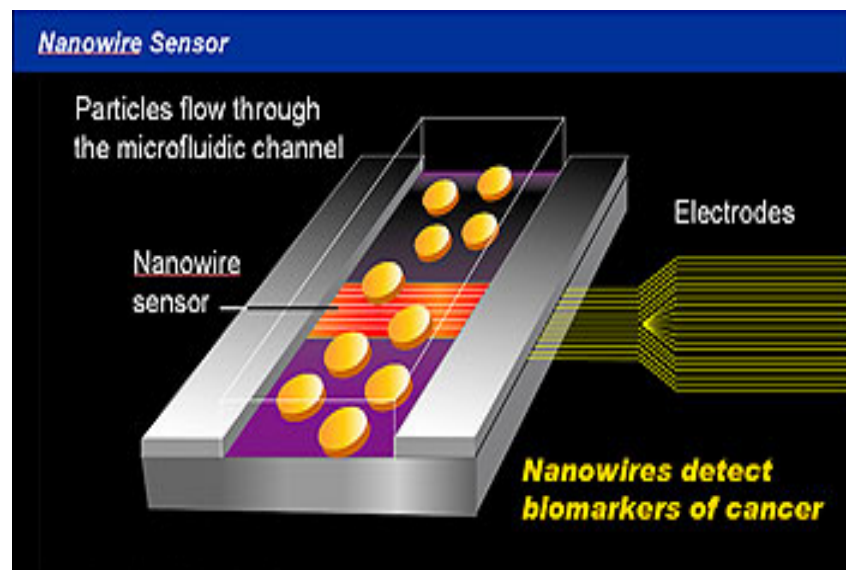
### Spectral finger-printing

- sub-ppt sensitivity
- $P_D > 99.99\%$
- $FAR < 1:10^9$
- Fast response  $< 1$  s

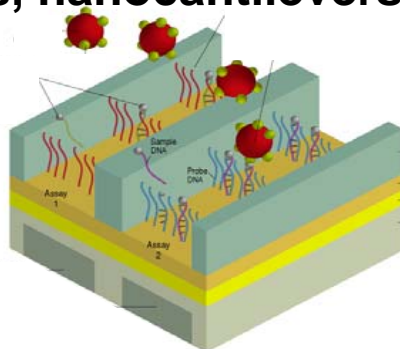


**Imagine... Nanosensors with ppq sensitivities and no false alarms.**

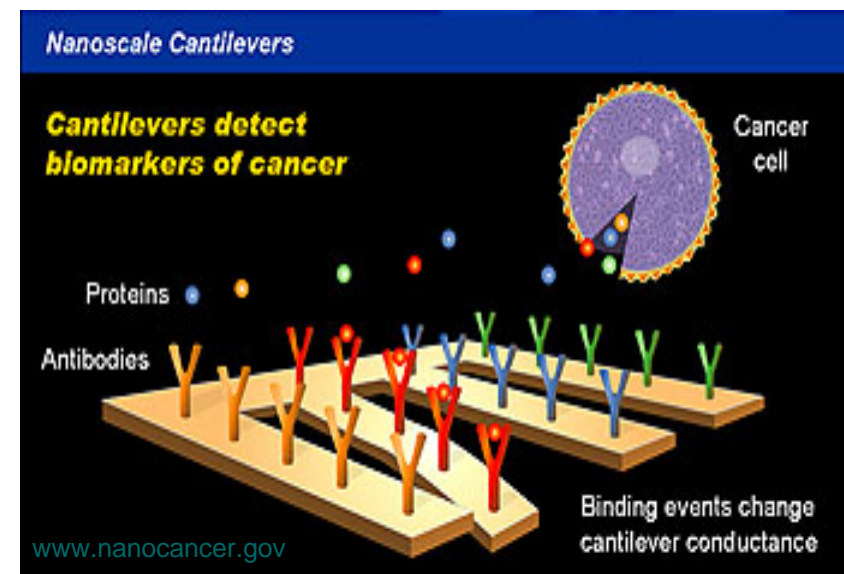
## Nanowire Sensors



- **Nanowires, CNTs, nanocantilevers, nanoparticles, quantum dots, nanoporous, magnetic materials**



## Nanomechanical Sensors

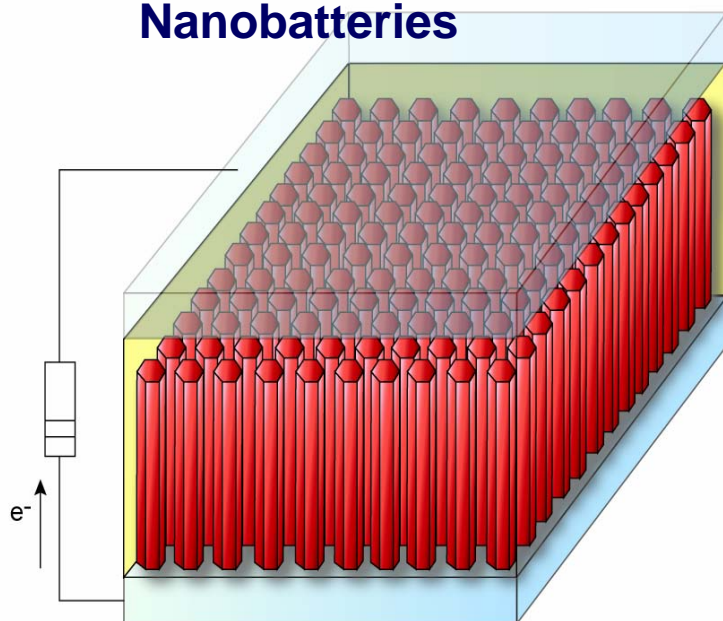


- **Application examples:**
  - Gas sensing
  - Protein/DNA detection
  - Particle detection
  - Chemical detection
  - Signal amplification (e.g.SPR)

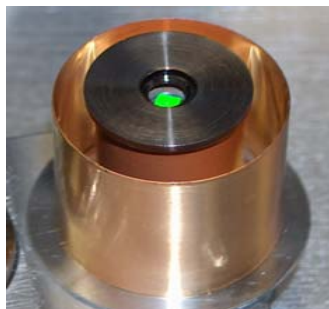
***Imagine... Integrated multi-functional nanosensor modules capable of multiplexed bioanalysis and physical sensing.***



## Nanobatteries

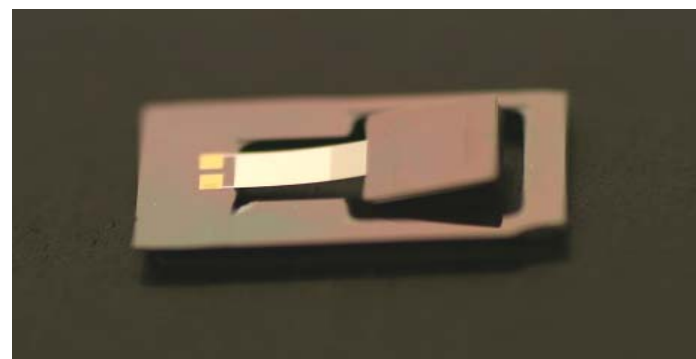
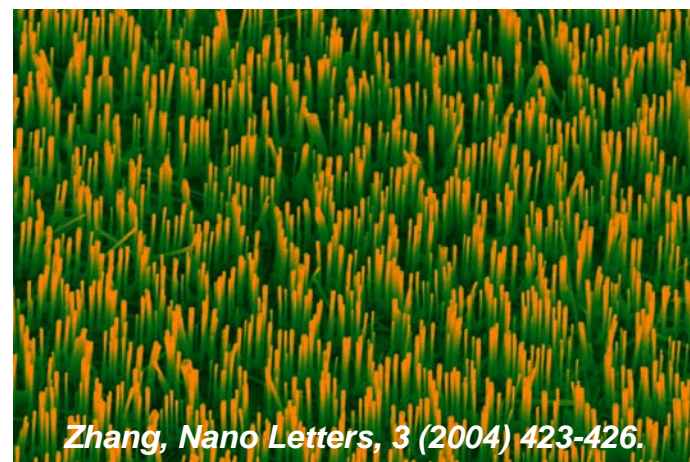


Zhang P. Yang, U.C. Berkeley



**Sandia National  
Laboratories Thermo-  
photovoltaic  
Power Converter**

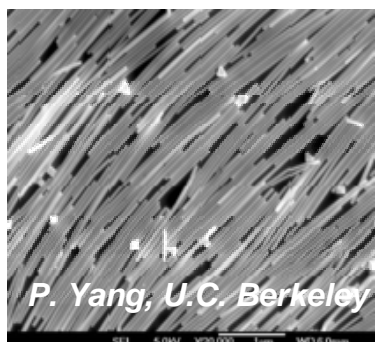
## Piezoelectric Energy Scavengers



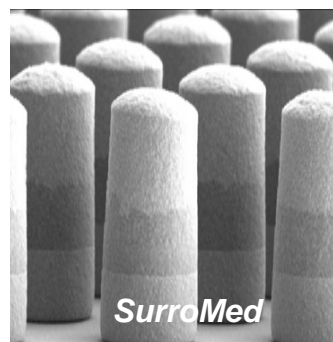
**Cornell Prototype MEMS Continuous-  
Mode Piezo-Cantilever Beta converter**

***Imagine... Never having to replace a battery.***

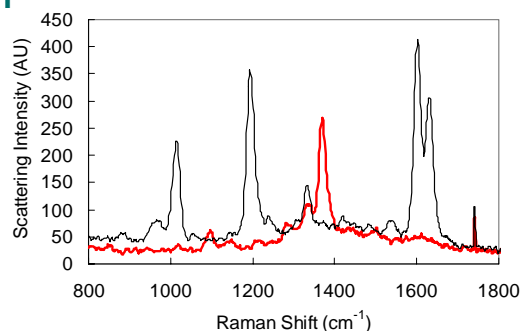
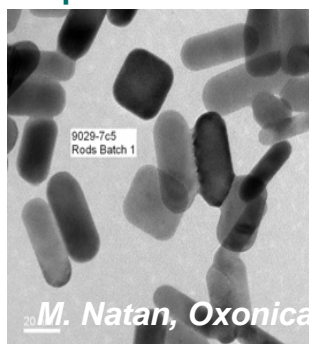




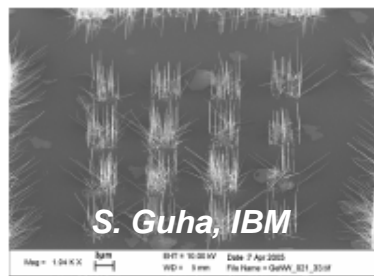
**Ag nanowires for explosives detection**



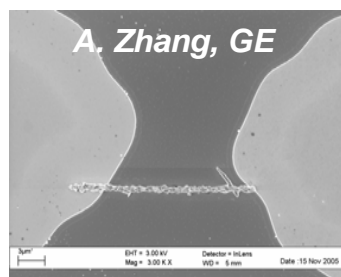
**Encoded nanowires**



**Au nanowires for multiplexed bioanalysis**



**Vertical selective growth of Ge nanowires for sensor and electronics applications**



**Assembled Co nanowire**

## • Goal:

- Develop new chemical, and biological nanosensors based on nanowires

## • Applications

- All types of sensing
- Energy harvesting
- Thermal management
- New class of nanosensors for the detection of biochemical warfare agents.

# Lessons Learned

## What are the opportunities for nanotechnology?

1. **Largest opportunities for nanotechnology are in enabling new systems**
2. **Look to nanotechnology to enable performance; not drive down cost.**
3. **Nanotechnology apps are best driven from top-down not bottom-up.**
4. **Multi-domain scaling is the key to performance-driven nanotechnology.**
5. **World competition is intense. Success in nanotechnology requires a vision, patience, and entrepreneurial spirit.**



# Summary



**Many, many new challenges remain (Challenge = Opportunity)**

## Microfluidic Analyzers

- Preparation (nanostructures)
- Preconcentration (nanochem)
- Nanoanalytics
- Nanodetectors (multiplexing)

## SERS Nanosensors

- Enhancement Factor (EM)
- Substrates
- Geometries
- Porous nanoparticles

## Nanowires

- Nanosensors
- Nanosolar cells
- Nanoenergy scavenging
- Thermal interfaces



**dpolla @ darpa.mil**